

The new AM CVn star in Hydra

Patrick A. Woudt[★] and Brian Warner[†]

Department of Astronomy, University of Cape Town, Private Bag, Rondebosch 7700, South Africa

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ABSTRACT

High speed photometry of the new AM CVn star in Hya (previously known as SN2003aw), spectroscopically identified by Chornock & Filippenko, shows it to have a superhump period of 2041.5 ± 0.3 s. We find a range of brightness from $V \sim 16.5$ to 20.3, presumably caused by variations in the rate of mass transfer. In the intermediate state the system cycles in brightness with a period of ~ 16 h and range ≥ 0.4 mag. There are sidebands to the principal frequencies in the Fourier transform which have constant frequency difference from the superhump harmonics.

Key words: techniques: photometric – binaries: close – stars: individual: 2003aw, cataclysmic variables

1 INTRODUCTION

The AM CVn stars are recognized to be cataclysmic variable stars (CVs) in which helium is being transferred from a degenerate donor to a degenerate accretor (see Warner (1995a) for a review of these stars). They parallel the behaviour of the hydrogen-rich CVs, having high-rate-of-mass-transfer (\dot{M}) stable discs (the nova-like variables), unstable high \dot{M} systems (nova-likes of the VY Scl type), intermediate \dot{M} dwarf novae, and very low \dot{M} systems perhaps permanently in a low state. All of the AM CVn stars are remarkable for their short orbital periods – ranging from possibly 5 min up to 65 min. The orbital modulations of brightness are of very low amplitude – the dominant period in the light curve is usually that of a superhump. This is the result of the very small mass ratios in these stars, which causes their accretion discs to become elliptical (e.g., Warner 1995a).

Until recently, there were nine definite and two possible AM CVn stars known, listed in Table 1 with a small selection of relevant references. The spectroscopic accreditation of a further member of this class, found in a search for supernovae, was announced by Chornock and Filippenko (2003) who observed the spectrum of supposed supernova 2003aw on the night of 2003 February 28, and found it to have a blue continuum with superposed broad and weak HeI emission lines at nearly zero redshift. KL Dra was similarly discovered in a supernova search (Jha et al. 1998). Alerted by Chornock and Filippenko’s announcement, we made photometric observations of the new candidate, which we will refer to in this paper as ‘2003aw’.

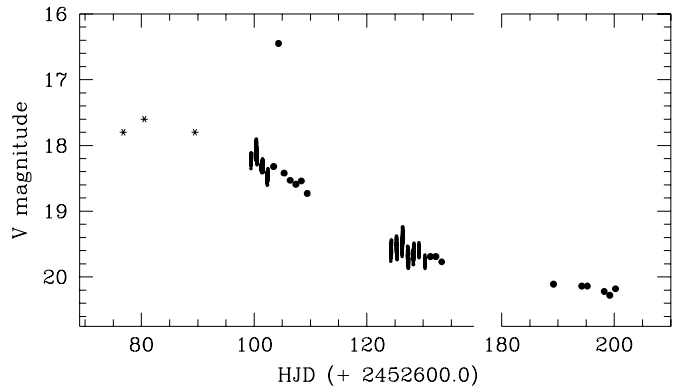


Figure 1. The long term light curve of ‘2003aw’.

2 PHOTOMETRIC OBSERVATIONS

We observed ‘2003aw’ with the 40-in and 74-in reflectors at the Sutherland site of the South African Astronomical Observatory (SAAO), using the University of Cape Town (UCT) CCD high speed photometer (O’Donoghue 1995) and no interposed filter, i.e., in ‘white light’. We calibrated our instrumental magnitudes by observations of a hot standard star. In addition, Retha Pretorius obtained some nightly brightness measurements for us, using the UCT CCD photometer on the 30-in reflector at Sutherland. The observing log of the high-speed (and snapshot) photometry of ‘2003aw’ is given in Table 2.

[★] E-mail: pwoudt@circinus.ast.uct.ac.za

[†] E-mail: warner@physci.uct.ac.za

Table 1. The AM CVn Stars

Object	V (mag)	P_{orb} (s)	P_{sh} (s)	References
RX J0806	21.1	321.25*		Israel et al. (2002); Ramsay, Hakala & Cropper (2002)
V407 Vul	19.9	569.38*		Cropper et al. (1998)
ES Cet	16.9	620.26		Warner & Woudt (2002)
AM CVn	14.1	1028.7	1051.2	Solheim et al. (1998); Skillman et al. (1999)
HP Lib	13.7	1102.7	1119.0	O'Donoghue et al. (1994); Patterson et al. (2002)
CR Boo	13.0 – 18.0	1471.3	1487	Wood et al. (1987); Patterson et al. (1997)
KL Dra	16.8 – 20	1500	1530	Wood et al. (2002)
V803 Cen	13.2 – 17.4	1612.0	1618.3	Patterson et al. (2000)
CP Eri	16.5 – 19.7	1701.2	1715.9	Abbott et al. (1992)
'2003aw'	16.5 – 20.3		2041.5	This paper
GP Com	15.7 – 16.0	2974		Nather, Robinson & Stover (1981); Marsh, Horne & Rosen (1991)
CE-315	17.6	3906		Ruiz et al. (2001); Woudt & Warner (2002)

Notes: * These have not yet been definitively established as orbital periods; P_{orb} is the orbital period; P_{sh} is the superhump period.

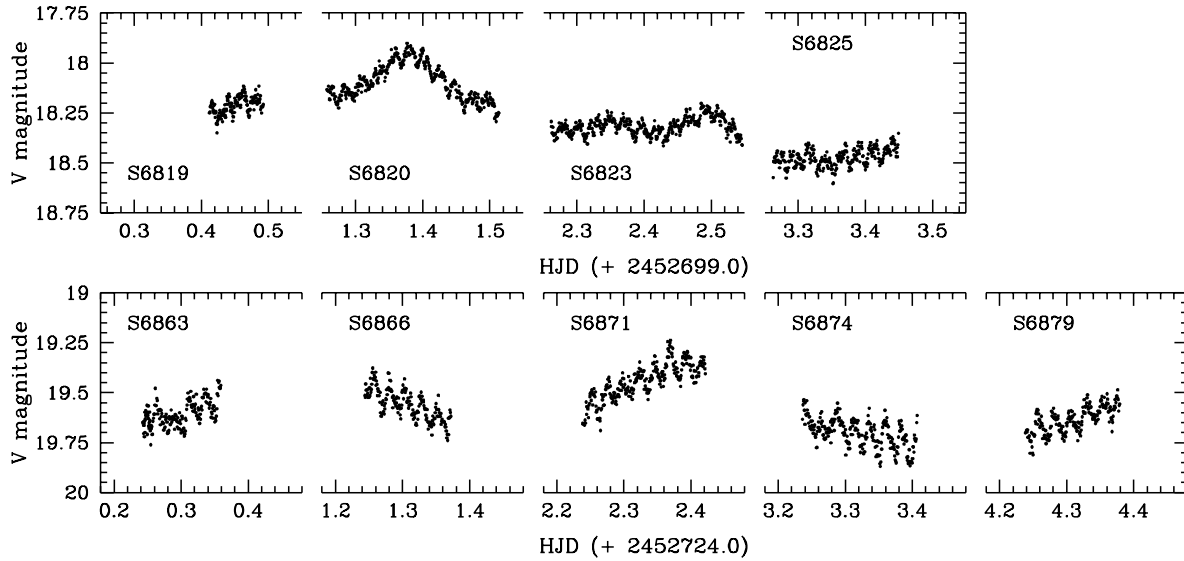


Figure 2. The light curves of ‘2003aw’, obtained in 2003 February and March. The upper set of light curves were taken when ‘2003aw’ was still relatively bright, the lower set were taken when ‘2003aw’ returned to a lower (intermediate) state.

3 LIGHT CURVES

3.1 The longer-term brightness variations

The long-term light curve, derived from the magnitudes listed in Table 2 and plotted in Fig. 1, shows a range of ~ 3.8 mag, but the length of coverage is too short to be sure that this represents the true full range. Superimposed on the large slow changes of mean brightness are rises and falls of ~ 0.3 mag during most of the runs, i.e., on times scales of hours (see also Fig. 2). There is also a very bright state that occurred when the system was already in a fairly high state, but lasted for less than a day. Apart from this last point, the light curve resembles those of V803 Cen (Patterson et al. 2000: hereafter P2000) and CR Boo (Patterson et al. 1997: hereafter P1997), both of which show ‘high states’ that bear some resemblance to superoutbursts, long sessions of cycling at an intermediate level that have been said to resemble dwarf nova outburst behaviour, and short visits to much lower states. In V803 Cen, the cycle time is 22 ± 1 h with a range of 1.1 mag, and in CR Boo the cycle time is ~ 19 h, with a range of 1.1 mag. These properties were

deduced from multi-site campaigns that were able to follow the cycling almost continuously. From our single site observations we cannot be so definite about ‘2003aw’, but with these two examples as our guide we note that the variations within each night, and from night to night, in the intermediate state are well fitted with a cycle time of ~ 16 h, but with an indeterminate range exceeding ~ 0.4 mag.

Although our observations are sparse, the evidence from Fig. 1 is that ‘2003aw’ had been in a low state prior to its discovery as a possible supernova, brightened and remained at $V \sim 17.5$ for about two weeks and steadily decreased in brightness over the subsequent three months. In this it resembles VY Scl behaviour, in which \dot{M} can change over a variety of time scales.

3.2 Rapid brightness variations

Fig. 2 shows the light curves obtained from our two weeks of high speed photometry, the first with the 40-in telescope when the star had just been recognised as an AM CVn star (Chornock & Filippenko 2003; Woudt & Warner 2003) and

Table 2. Observing log of high speed and snapshot photometry of ‘2003aw’.

Run No.	Date of obs. (start of night)	HJD of first obs. (+2452000.0)	Length (h)	t_{in} (s)	Tel.	V (mag)
S6819	2003 Feb 28	699.41240	2.19	45, 60	40-in	18.2
S6820	2003 Mar 01	700.25748	6.15	60	40-in	18.1
S6823	2003 Mar 02	701.26168	6.83	60	40-in	18.3
S6825	2003 Mar 03	702.26245	4.48	60	40-in	18.5
S6830	2003 Mar 04	703.46834		180	30-in	18.3
S6834	2003 Mar 05	704.32556		60, 120	30-in	16.5
S6839	2003 Mar 06	705.32117		120	30-in	18.4
S6846	2003 Mar 07	706.39227		120, 300	30-in	18.5
S6851	2003 Mar 08	707.41999		200, 300	30-in	18.6
S6854	2003 Mar 09	708.35306		240	30-in	18.5
S6861	2003 Mar 10	709.41747		180, 240	30-in	18.7
S6863	2003 Mar 25	724.24288	2.79	30, 60	74-in	19.6
S6866	2003 Mar 26	725.24377	3.08	60	74-in	19.6
S6871	2003 Mar 27	726.23852	4.39	60	74-in	19.4
S6874	2003 Mar 28	727.23629	4.58	60	74-in	19.7
S6879	2003 Mar 29	728.23867	3.37	60	74-in	19.6
S6884	2003 Mar 30	729.23656	0.86	60	74-in	19.6
S6891	2003 Mar 31	730.31131	0.95	60	74-in	19.8
S6894	2003 Apr 01	731.27721		120, 300	30-in	19.7
S6899	2003 Apr 02	732.24219		120, 200	30-in	19.7
	2003 Apr 03	733.28889		180, 180	30-in	19.8
	2003 May 29	789.19547		180, 200, 300	30-in	20.1
	2003 Jun 03	794.19963		90	74-in	20.1
	2003 Jun 03	795.20332		90	74-in	20.1
	2003 Jun 07	798.19472		60	74-in	20.2
	2003 Jun 08	799.19673		60	74-in	20.3
	2003 Jun 09	800.19639		90	74-in	20.2

Note: t_{in} is the integration time.

was quite bright, and the second when it had faded and we were fortunately observing with the larger telescope.

3.2.1 The superhump modulation

In all of the light curves there is a clear modulation with a period of 2041.5 s (± 0.3 s) and range of ~ 0.1 mag. This persistence of what we suppose to be superhump modulation into lower states of mass transfer is similar to what is found in V803 Cen (P2000) and CR Boo (P1997). The ephemeris for minimum light, derived from the data set obtained during the intermediate state, is given in Eq. 1.

$$\text{HJD}_{\min} = 245\,2724.25281 + 0^{\text{d}}023628(\pm 3) \text{ E.} \quad (1)$$

Fourier transforms (FTs) for the set of high state observations (runs S6819 – S6825 of Table 2) and for the intermediate state observations (runs S6863 – S6891) are shown in Fig. 3. For the light curves in the intermediate state, an individual mean and slope has been subtracted in the FT. In the high state, runs S6820 and S6823 were prewhitened at the low frequency modulation visible in Fig. 2, after which individual mean values were subtracted in the FT. The fundamental and several harmonics show that the profile of the superhump is highly non-sinusoidal, as has been found in other AM CVn stars. Table 3 lists the measured frequencies (with uncertainties from non-linear least squares fits) and amplitudes of the fundamental and harmonics.

In our first observations, the dip near the maximum of the profile initially appeared to be drifting slowly relative to the hump itself, which led us to announce the possibility of a

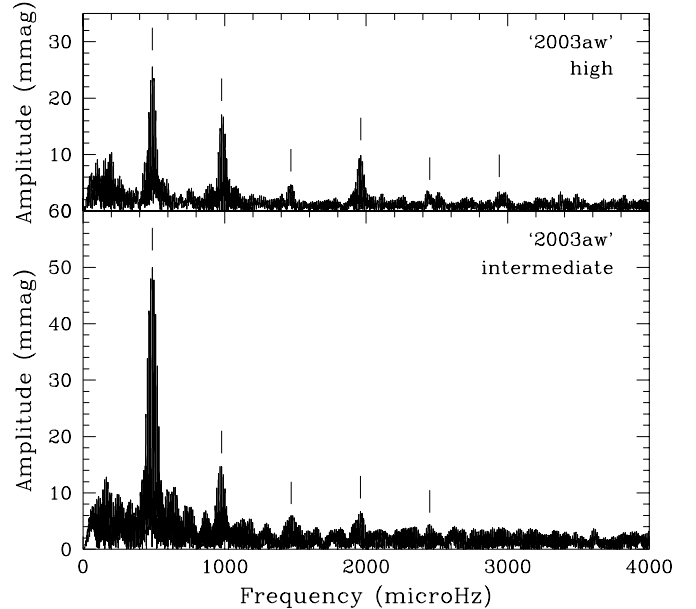


Figure 3. The Fourier transforms of ‘2003aw’ in a high state (upper panel) and intermediate state (lower panel). The frequencies listed in Table 3 are marked by vertical bars.

shallow eclipse (Woudt & Warner 2003). Later observations, however, showed it to be a fixed feature in the profile, very similar to the profile in ES Cet (Warner & Woudt 2002).

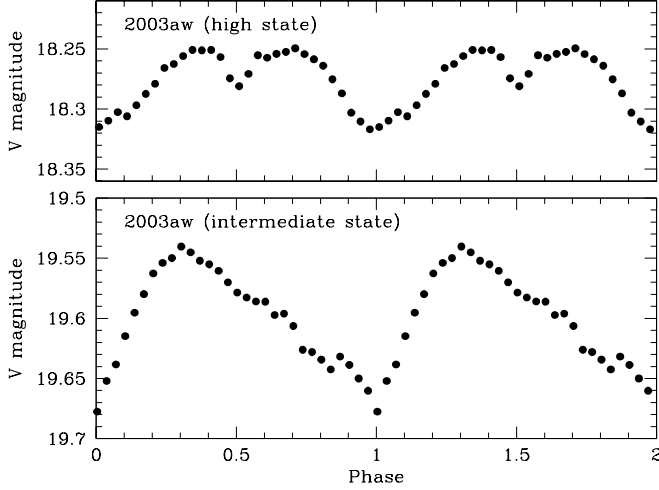


Figure 4. The average light curve of ‘2003aw’ in a high state (upper panel) and intermediate state (lower panel). The latter is phased on the ephemeris given in Eq. 1; the high state light curve is relative to the same period, but phased independently (due to the long gap between the two groups of observations) to match the minimum at intermediate state.

Table 3. Frequencies of the superhump modulation and its harmonics; amplitudes (in mmag) are given in square brackets.

ID	High state Frequency μHz	Intermediate state Frequency μHz
Ω_{sh}	489.91 ± 0.09 [25.1]	489.84 ± 0.03 [49.9]
$2 \Omega_{sh}$	979.54 ± 0.13 [16.9]	979.70 ± 0.12 [14.7]
$3 \Omega_{sh}$	1469.30 ± 0.46 [4.6]	1469.54 ± 0.28 [6.0]
$4 \Omega_{sh}$	1961.96 ± 0.22 [9.8]	1959.31 ± 0.24 [7.1]
$5 \Omega_{sh}$	2448.39 ± 0.75 [2.8]	2449.34 ± 0.37 [4.5]
$6 \Omega_{sh}$	2940.40 ± 0.61 [3.5]	—

3.2.2 Sidebands

In addition to the superhump fundamental and harmonics in the FTs there are signals at neighbouring frequencies. This is illustrated in Fig. 5 where the second harmonics in both high and intermediate states are accompanied by distinct sidebands of comparable amplitudes. The FT for the high state, prewhitened with the superhump frequency and its harmonics, is given in Fig. 6, which shows the remaining sideband power at the fundamental, second and fourth harmonics. The sideband frequencies are listed in Table 4. In

Table 4. Sideband frequencies.

ID	High state Frequency μHz	$\Delta\nu$ μHz	Intermediate state Frequency μHz	$\Delta\nu$ μHz
$\Omega_{sh} - \Delta\nu$	470.5 ± 0.4 [5.6]	19.4		
$3\Omega_{sh} - \Delta\nu$	1449.8 ± 0.5 [4.4]	19.5	1454.5 ± 0.3 [4.9]	15.0
$5\Omega_{sh} - \Delta\nu$	2430.1 ± 0.8 [3.7]	19.5*		

Note: * This is relative to the predicted frequency of the fourth harmonic (which is itself of low amplitude and a less reliable frequency).

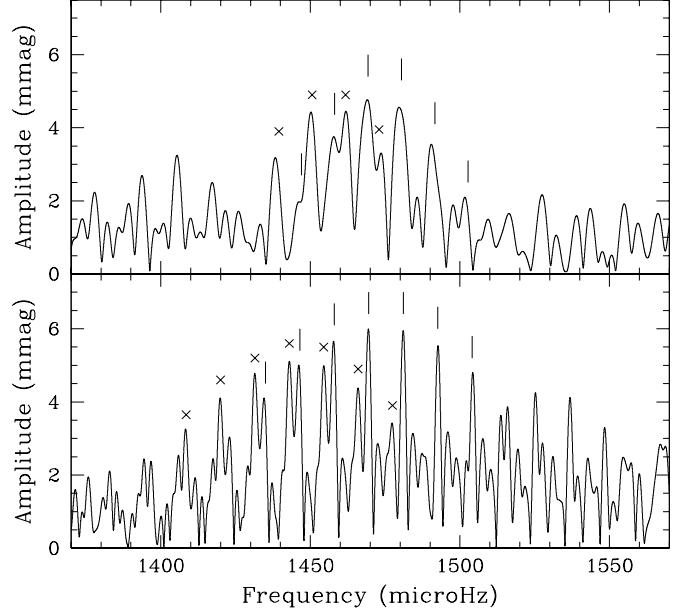


Figure 5. The Fourier transforms of ‘2003aw’ in a high state (upper panel) and intermediate state (lower panel) centred on the second harmonic of the superhump frequency. The harmonic (and its aliases) is marked by the vertical bars, the sideband is marked by crosses.

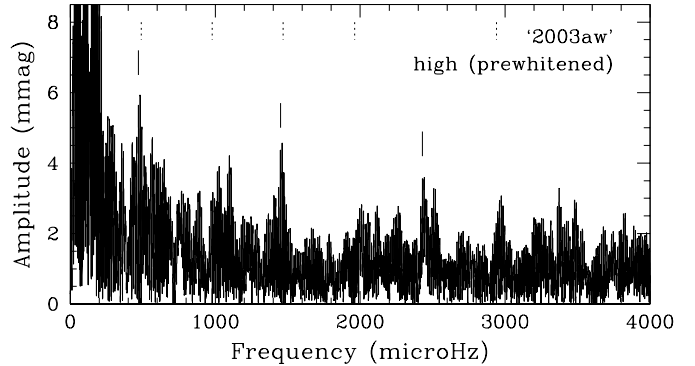


Figure 6. The Fourier transforms of ‘2003aw’ in a high state after prewhitening at the frequencies listed in Table 3 (marked by dotted vertical bars). The solid vertical bars show the sidebands.

all cases there is an aliasing problem which could result in the quoted values of $\Delta\nu$ being decreased by $\sim 11.8 \mu\text{Hz}$.

The consistency of the measured values of $\Delta\nu$ in the high state speaks for their reality. The frequency splitting of $19.5 \mu\text{Hz}$ is equivalent to a period of 14.2 h, which is suggestively close to the ~ 16 h cycling in brightness described in Section 3.1. The $\Delta\nu$ measured in the intermediate state is equivalent to 18.5 h.

These results for ‘2003aw’ are in strong contrast to what has been seen in other AM CVn stars. The dwarf nova-like cycling in CR Boo did not produce sidebands (P1997); whether the cycling in V803 Cen does is not yet known as P2000 found the FT too complicated to dissect. Another contrast is that in AM CVn itself; although constant values of $\Delta\nu$ are seen, they are relative to the orbital frequency, not the superhump frequency (Skillman et al. 1999). A simi-

lar situation obtains in HP Lib (Patterson et al. 2002) and CR Boo (P1997). There is, as a result, some confusion over what is happening in ‘2003aw’: could we be seeing an orbital hump rather than a superhump? Is the ~ 16 h cycling due to precession of a disc rather than dwarf nova outbursts?

4 DISCUSSION

Despite its initial discovery via a supernova search, ‘2003aw’ belongs to the class of AM CVn stars and is not a supernova, nor is there a galaxy nearby as initially thought (the supposed galaxy on the sky survey plate is in fact a fuzzy image of ‘2003aw’ in a low state). Fortunately, however, it was mistaken for a galaxy; ‘2003aw’ might otherwise have remained anonymous.

The short-lived outburst on 2003 March 5, coming when ‘2003aw’ was already in a high state, resembles the behaviour in some intermediate polars (Schwarz et al. 1988; van Amerongen & van Paradijs 1989). If these are caused by temporary increases in \dot{M} from the secondaries then it implies similar behaviour in low mass hydrogen-rich main sequence stars and very low mass helium white dwarfs. On the other hand, if the short outbursts are caused by temporary storage and release of mass into the magnetospheres of the intermediate polars (e.g., Taam & Spruit 1989) this implies a substantial magnetic field on the primary of ‘2003aw’.

A pleasing aspect of the new AM CVn star in Hya is that it knows its place in the helium-transferring hierarchy. It has previously been pointed out (Warner 1995a,b,c) that the theoretical reduction of \dot{M} with increasing P_{orb} , together with the destabilizing effect of irradiation on the secondary (Wu, Wickramasinghe & Warner 1995) produces stable high \dot{M} at the shortest periods, VY Scl behaviour at intermediate periods, and low \dot{M} , probable long-interval large amplitude dwarf novae at the longest periods. Each of the recently discovered AM CVn stars, including ‘2003aw’, fits into this pattern. The current observational boundaries (Table 1) are: Stable high \dot{M} for $P_{orb}(s) \lesssim 1200$, VY Scl $1200 \lesssim P_{orb}(s) \lesssim 2500$, Low state $P_{orb}(s) \gtrsim 2500$. As more AM CVn stars are discovered, it will be interesting to see whether the boundaries are sharp or if there is some fuzziness to them.

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